Title
Does ethnicity influence the short-term adaptation to first reading correction?

Journal
Optometry and vision science : official publication of the American Academy of Optometry, 89(4)

ISSN
1040-5488

Authors
Vedamurthy, Indu
Lin, Meng
Tong, Jianliang
et al.

Publication Date
2012-04-01

DOI
10.1097/opx.0b013e318251d2f2

Peer reviewed

1040-5488/12/8904-0435/0 VOL. 89, NO. 4, PP. 435–445
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Does Ethnicity Influence the Short-Term Adaptation to First Reading Correction?

Indu Vedamurthy*, Meng Lin†, Jianliang Tong*, Thao N. Yeh‡, Andrew D. Graham§, Harry Green‡, Shiyin Linda Wang||, Amrita Sabharwal||, and Clifton M. Schor†

ABSTRACT

Purpose. Ethnic variations in accommodative amplitude (AA) are not uncommon. Accommodation can become reduced in response to short-term wear of first near spectacles. Whether ethnicity has an influence on the magnitude of this adaptation is not well understood. We investigated the impact of first near spectacles on changes in AA and on convergence cross-link interactions in incipient presbyopes of Chinese and Caucasian ethnicities.

Methods. Forty-one subjects (22 Caucasians and 19 Chinese) aged 36 to 44 years completed the study. Accommodative stimulus response function, AA, and AC/A and CA/C ratios were measured before and after single vision reading spectacles were used for near tasks over a 2-month period and then again 2 months after discontinuing near spectacle wear.

Results. After wearing reading spectacles for 2 months, the accommodative stimulus response slopes and AC/A and CA/C ratios remained invariant irrespective of ethnicity. The accommodative, but not vergence, bias decreased ($p < 0.05$). The nearpoint of accommodation shifted distally producing an average decrease in AA of 0.52 D from baseline ($p < 0.05$). Recovery to near baseline values occurred after discontinuing the reading glasses for 2 months. Differences based on ethnicity were not significant. The baseline AA vs. age plots showed steeper slopes for Chinese than the Caucasian subjects in the sample.

Conclusions. The pattern of adaptation by accommodation and cross-link interactions to short-term first reading spectacles is not influenced by ethnicity.
(Optom Vis Sci 2012;89:435–445)

Key Words: accommodation, convergence, ethnicity, near spectacles, adaptation

Differences in the accommodative response between different ethnic groups have not been well studied.[1] Particularly, direct comparisons between Caucasian and Chinese populations who are thought to differ in the time of onset of presbyopic signs, and initial add power in early presbyopia, are lacking. Edwards et al.[2] measured the clinical norm for accommodative amplitude (AA) in Chinese subjects in Hong Kong. They found it to be lower compared with the age-matched norm for presumably Caucasian subjects derived from another study conducted in New York.[3] Ong[4] found that the onset of presbyopia occurred at age 35 years and absolute presbyopia was reached by age 42 years in subjects of Southeast Asian ethnicity. Ong used near-add requirements of +1.00 D and +2.00 to +2.50 D to define onset and absolute presbyopia, respectively. This time course of presbyopia is earlier than what is considered normal for Caucasian subjects who experience the onset of presbyopia at age 40 years and reach complete presbyopia by age 51 years.[3]

The reasons for early onset of presbyopia are mutlifactorial.[5,6] Miranda[5] conducted an international survey study and reported a causal link between environmental factors and the onset of presbyopia marked by AAs of 3.75 D or less. Miranda concluded that people living in countries that are in close proximity to the equator and where people are exposed to either greater solar radiation or high average temperature require near-addition lenses sooner than those who are less exposed. Although Florida and Hong Kong share similar climatic conditions, the age at first near prescription in Florida was typically 42 years.[2,5] Based on this observation, Edwards et al.[2] suggested that long-term environmental influences might not completely account for their findings in their Chinese sample. Weale[6] proposed an alternative explanation based on dif-

*PhD
†OD, PhD
‡OD
§MA
||BS
Brain & Cognitive Sciences, University of Rochester, Rochester, New York (IV), and Clinical Research Center (ML, TNY, ADG, HG, SLW, AS), School of Optometry (ML, HG, CMS), Vision Science Group (JT, CMS), University of California, Berkeley, Berkeley, California.

ferences between the pupil sizes of Chinese and Caucasian subjects and hypothesized an iridogenic role in human accommodation. On the other hand, difficulties arise in interpreting available data. For example, Ong's study was conducted on Southeast Asian refugees who may have had nutritional deficiencies, and the subject sample was drawn from clinic patients with anisometropia and subnormal corrected visual acuities. In addition, both Edwards et al. and Ong did not include Caucasian (control) participants in their studies.

Several studies have investigated the effects of wearing near-vision or reading spectacles on AA in young adults and incipient presbyopes.[7–9] These studies did not factor in differences based on ethnicity. Shapiro et al.[8] showed that young adult subjects routinely overaccommodated immediately after wearing +2 D near spectacles, and no adaptation of accommodative response occurred after 30 min of reading with near spectacles. Rosenfeld et al.[7] found monotonically increasing leads of accommodation with increasing power of plus near-add lenses worn in combination with distance spectacles. It has also been found that distance visual acuity is reduced in emmetropes after wearing reading spectacles for intermediate or distance work. The longer the reading spectacles were used to view beyond the focal point, the greater the impact on distance acuity.[10] Recently, our group showed that regular use of near-vision correction in the early stages of presbyopia could have an impact on accommodative ability. We investigated the effects of first near spectacles on the accommodative response in pre-presbyopic subjects (21 to 30 years of age) and incipient presbyopic subjects (38 to 44 years of age).[9] Our results showed that the near and far points of accommodation receded after wearing reading spectacles for 2 months and did not return to baseline after 2 months of recovery period without wearing near spectacles. These changes were age invariant and suggest greater functional consequence to the incipient presbyopic subjects who have limited AAs compared with the younger subject group.

Near-vision plus-lens corrections also produce a conflict between the stimulus to accommodation and convergence. It has been demonstrated that conflicts produced by wearing a telestereoscope for 30 min, which produces a smaller stimulus to accommodation than to convergence, can decrease the strength of coupling (gain) between accommodation and vergence (AC/A ratio).[11,12] Changes in accommodation with increasing age include a reduction of the amplitude of accommodation and increased effort to accommodate in the saturation range of the response. These age-related changes produce conflicts between the effort needed to accommodate and that needed to converge on near stimuli, resulting in an increase of the AC/A ratio[13] and a decrease of the accommodation response stimulated by efforts of convergence (CA/C ratio).[14] Adaptation of the AC/A and CA/C ratios could help alleviate problems with maintaining binocular alignment during the development of incipient presbyopia.

In this study, we compared the influence of first near spectacles on AA and interactions between accommodation and binocular eye alignment in Chinese and Caucasian subjects. We examined incipient presbyopic subjects to determine whether the accommodative stimulus response (ASR) function, AA, AC/A ratio, and CA/C ratio differed before and after 2 months of wearing reading glasses. We also examined whether these characteristics recovered after discontinuing wear of reading glasses for 2 months and whether there were differences in any of these outcomes between Caucasian and Chinese subjects. With normalized testing conditions and methodology, if Chinese subjects indeed have lower AAs than their Caucasian counterparts and respond differently to near-addition lenses, then different reading prescription strategies may be required based on ethnicity. Distance refraction is not independent of near correction.[9,10] To reiterate our previous work, 2 months of reading glass wear produced both a reduction in AA and receded far point of accommodation. If there were differences based on ethnicity, then the group showing large effects may report a greater dependence on near-reading correction and an increased blur for distance vision, unless a correction is incorporated to offset the refractive shift.

METHODS

Subjects

Forty-one (22 Caucasian and 19 Chinese) subjects in the age range 36 to 44 years, recruited anew for this study, completed all study visits. Subjects self-categorized for ethnicity and were required to identify both parents as being either fully Caucasian or fully Chinese to be eligible for the study. After a thorough explanation of the goals, risks, and benefits of the study, informed consent was obtained from each subject. This study adhered to the tenets of the Declaration of Helsinki and was approved by the Committee for the Protection of Human Subjects at the University of California at Berkeley.

Study Protocol

The study required a total of four visits by each subject. Subjects were asked to complete a telephone screening before being invited on-site for a standard comprehensive eye examination that also included binocular refraction to uncover the presence of latent hyperopia. Subjects had to meet the basic ethnicity requirements for classification as Caucasian or Chinese[15] and eyeglass prescription requirements, which included not currently wearing reading glasses or removing their habitual distance (myopic correction) spectacles to see clearly at near. We recruited only subjects who needed near-vision correction, expressed a desire for reading glasses, and would be the most likely to adhere to the daily wearing requirements of the study protocol. In addition, subjects with ocular pathology or systemic conditions with ocular manifestation were excluded. Eligibility for the study was determined at the initial eye examination, according to the criteria detailed in Table 1. A total of 80 subjects were screened on-site, and 55 subjects were found eligible to participate. Of the 55, 14 subjects dropped out at various stages of the study due to reasons shown in Fig. 1. Only one subject reported discomfort/headache with reading glasses after the initial adjustment period and eventually dropped out. The distribution of refractive error for both ethnicities is shown in Fig. 2. In the Chinese group, there were 14 myopes, 4 emmetropes, and 1 low hyperope. The Caucasian group consisted of 13 myopes, 8 emmetropes, and 1 low hyperope. In the present sample, three Chinese and five Caucasian (myopic) subjects wore contact lenses for distance correction.

Qualified subjects were asked to return for baseline measurements of ASR function and AC/A and CA/C ratios on a Badal optometer mounted on a Wheatstone-mirror haploscope. Subjects

TABLE 1.
Inclusion criteria for refractive and binocular vision status

Refractive and binocular vision requirements	
Best-corrected VA	20/20 or better in each eye
Refractive error	
Sphere[a]	≤±4.50 D, <1.00 anisometropia
Cylinder	≤−1.00 D
Near-add demand (NRA/PRA)	
Age 36–39 yr	None
Age 40–44 yr	≤+0.75 D
Tropia (free space)	None
Distance phoria (free space)	
Exophoria	≤2 pD
Esophoria	≤1 pD
Near phoria (phoropter)	
Exophoria	≤6 pD
Esophoria	≤4 pD
Gradient AC/A (von Graefe technique)	2/1 to 6/1
Monocular accommodative amplitude (push-up)	
Age 36–39 yr	≥15–age/4
Age 40–44 yr	≥3.0 D

[a]Exceptions were made if subject had longstanding myopia.
pD, prism diopters.

were prescribed +1.50 D single vision additions over their up-to-date distance prescription and were asked to wear them only for near tasks, such as reading or computer work, for a minimum of 3 h per day, 5 d per week, over a 2-month period. A +1.50 D add was chosen because our previous work has shown that this add power was sufficiently strong to produce adaptive changes in AA in a mixed group of 36- to 44-year-old subjects uncategorized by ethnicity. Subjects completed a weekly questionnaire to ensure compliance with the minimum wearing requirements. Those subjects who habitually wore contact lenses on a daily basis were instructed to wear single vision +1.50 D readers over their contact lenses for near work. After using the study reading spectacles for 2 months, all subjects returned for another set of optometer-haploscope measurements and surrendered the study reading spectacles at that time. Subjects returned for a final set of measurements after discontinuing wear of the study reading spectacles for 2 months. During the postwear recovery period, subjects were required not to use reading glasses for near work. A symptoms questionnaire was administered before, during, and after the use of reading glasses to monitor visual or malaise symptoms.

Instrumentation and Measurements

A pair of Badal-optometer stigmascopes built into a Wheatstone-mirror haploscope was used to obtain subjective measures of accommodative response and convergence response, as described in our earlier report.[9] Each stigmascope consisted of a 10 D Badal lens that imaged a variable focus stigma (0.5 mm point source of light). A pair of beam splitters was used to optically superimpose the stigmas onto the accommodative target (~6/9 print size) placed at 1 m from the subject (see Fig. 3). The Badal lens was mounted such that its secondary focal point coincided with the anterior focal point of the eye. This allowed for changes in the dioptric vergence of the stigma without changing the magnification[16] and to linearize the scale of accommodation.[17,18] A crosshair was superimposed in the stigma pupil to reduce the depth of focus. Subjects adjusted the focus of the stigma/crosshair by turning a knob to move the stigma along an optical track toward or away from the Badal lens. The distance between the stigma and the Badal lens was used to compute the accommodative response. The stigma/crosshair was in sharp focus when it was optically conjugate with the retina to within ±0.125 D.

For accommodation measurements, subjects were asked to fixate and focus on the text target with the left eye and then to adjust the knob to bring the crosshair to sharp focus. The right eye was occluded. A series of negative lenses was used in a randomized order to increment the accommodative stimuli to the left eye until the maximum minus lens stimulus to accommodation was reached. We used 1 D lens steps for subjects in the age range 36 to 39 years. To increase the number of data points to generate the ASR curve in subjects aged 40 years or older, who normally have relatively limited AAs, we used half diopter lens steps. For each lens, seven measurements were obtained. For the different lens powers over the accommodative range (with different mean accommodative responses), the within-subject variability for repeated measurements[19] was low as indicated by the low coefficient of variation (COV) (see Fig. 4, COV range: 0.04–0.18, n = 5) in pilot subjects in the age range included in the study. The COV is relatively higher only for small vs. large accommodative stimuli, which are normally outside the linear range of accommodation (Fig. 4).

A possible drawback to the usage of two lens steps is that the sensitivity of the AA estimate may be reduced with larger step sizes. In a control experiment (n = 5), we compared the AAs derived using 1 and 0.5 D in the same set of subjects. The differences in AA estimated using 1 vs. 0.5 D was 0.06 ± 0.06 D (mean ± 1 SD). The average slopes of the ASR functions measured with 1 and 0.5 D steps were 0.86 and 0.89 (and average SE of the slopes were 0.06 and 0.04), respectively, indicating insignificant differences. Moreover, the primary focus of this study is to examine the relative changes from baseline with treatment. Therefore, the choice of steps would not change the main results as long as the same step size is used within subject across study visits.

For gradient response AC/A measurements, subjects began by focusing the right and the left eye stigmas as described above with no lens stimulus. After this, an occluder was placed on the rear side of the right beam splitter so that the right stigma remained visible but the accommodative text target was blocked from that eye's view. This opened the feedback loop for convergence (open-loop disparity condition); however, the monocular blur feedback to accommodation was closed loop. Subjects were asked to focus the accommodative text target and fixate on a central letter target with their left eye. They then rotated the right arm of the haploscope so the perceived horizontal direction (azimuth) of the right stigma was aligned with that of the central letter target and the left eye stigma (dichoptic vernier task). Displacing the right stigma vertically prevented binocular fusion of the two stigmas. The azimuth rotation angle of the right haploscope arm was taken as the measure

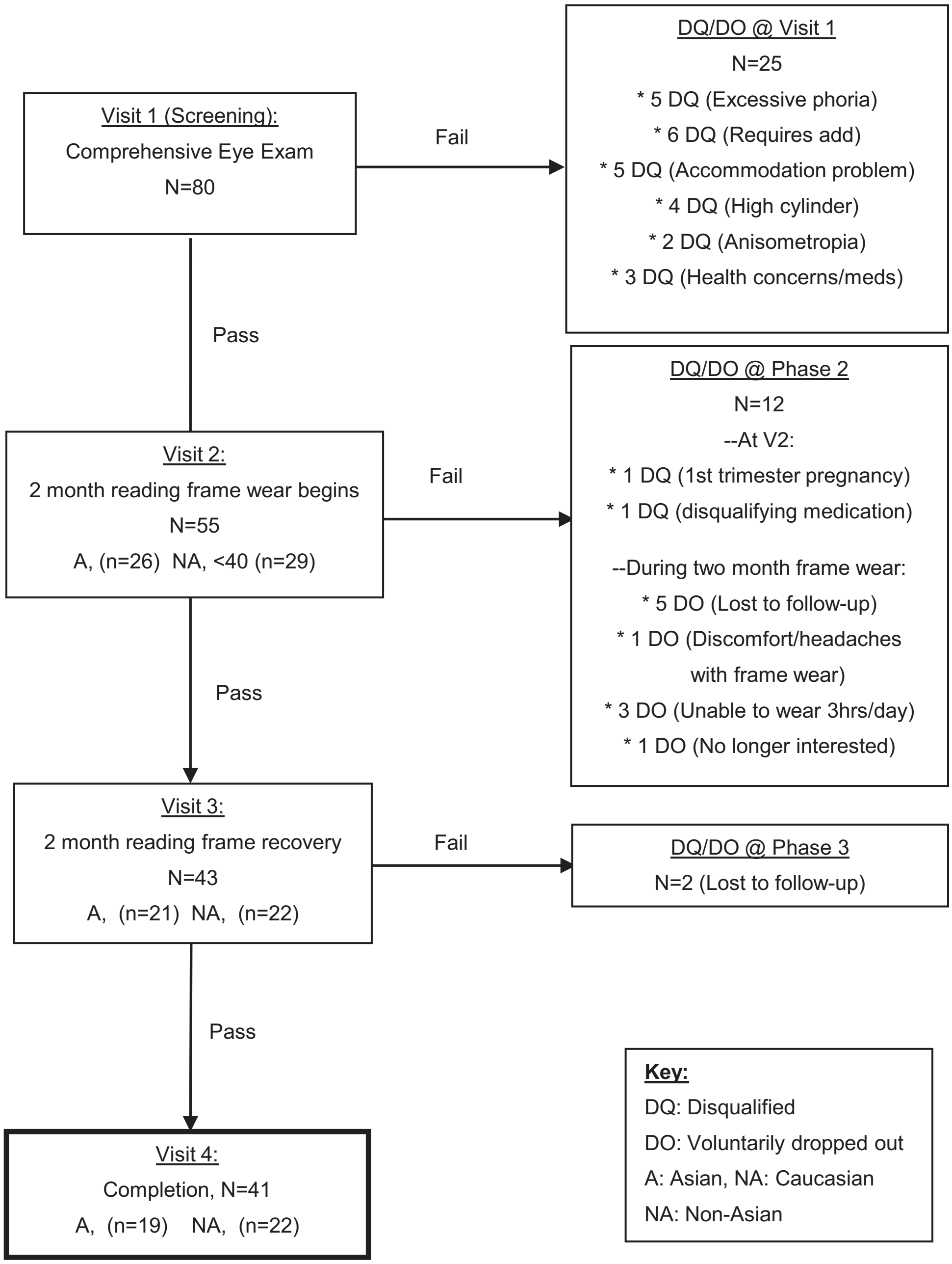

FIGURE 1.
Summary of subject enrollment status by study visits.

of convergence. The haploscope arm rotates about a pivot point coincident with the eye's center of rotation, thereby preventing retinal image translation of the stigma during azimuth adjustments Accommodation was stimulated with ophthalmic lenses placed before the left eye over a range of dioptric powers starting from +1 to −5 D in 1 D steps in 36 to 39 year olds and +1 to −3 D in 0.50 D steps in subjects aged 40 years and older. Because subjects viewed an accommodative text target placed at 1 m, a +1 D lens would stimulate 0 D accommodative demand for that distance.

During CA/C measurements, subjects were instructed to binocularly fuse a low spatial frequency difference-of-Gaussians (DoG) target while the disparity stimulus to convergence was varied with ophthalmic prisms placed before both eyes in a randomized order over a range of −1.0 to +4.0 meter angles (MA) in 1.0 MA steps. Convergence responses were assumed to equal the vergence stimuli as long as the DoG target could be fused.[20,21] The low spatial frequency (0.2 cpd) DoG target opened the blur feedback to accommodation owing to its large depth of field.[22] The convergence response error (fixation disparity) to this stimulus is $<0.25°$.[23]

Adequate training was provided to the subjects, and the examiners made sure that the subjects understood the tasks. Seven measurements were obtained for each of the lens or disparity stimuli for AC/A and CA/C ratio measurements, respectively.

Analysis of ASR and AC/A and CA/C Ratios

We estimated several parameters for ASR and AC/A and CA/C ratios using the analysis methods described in our previous report.[9]

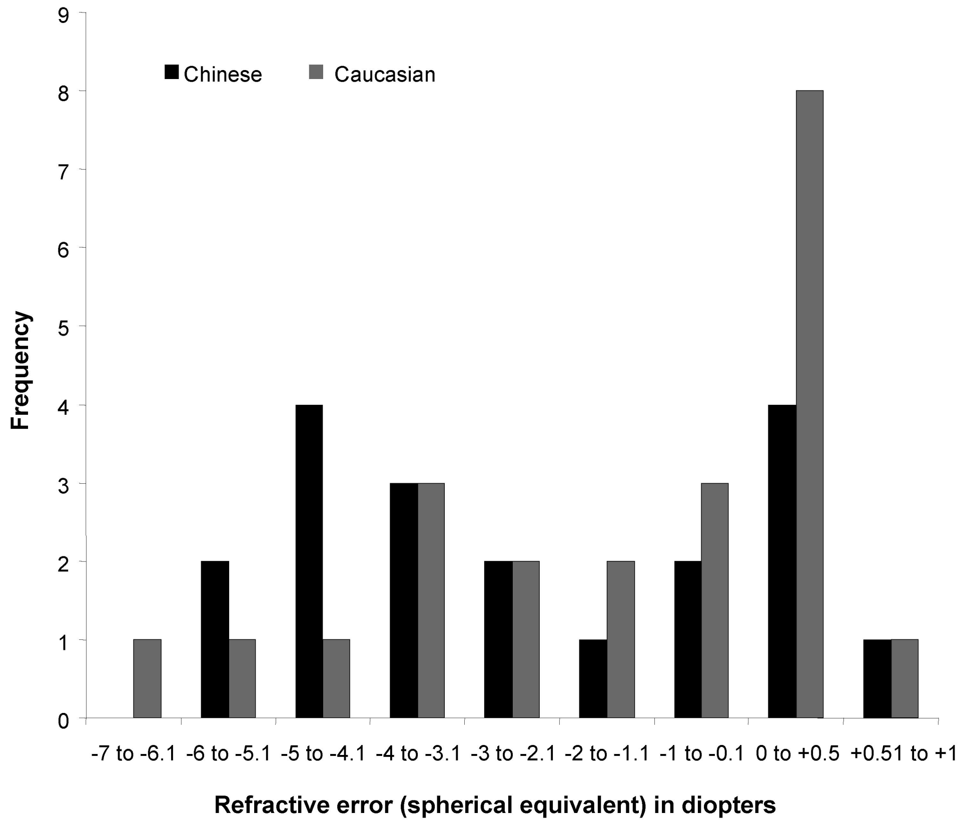

FIGURE 2.
The distribution of refractive errors in Chinese and Caucasian subjects by age.

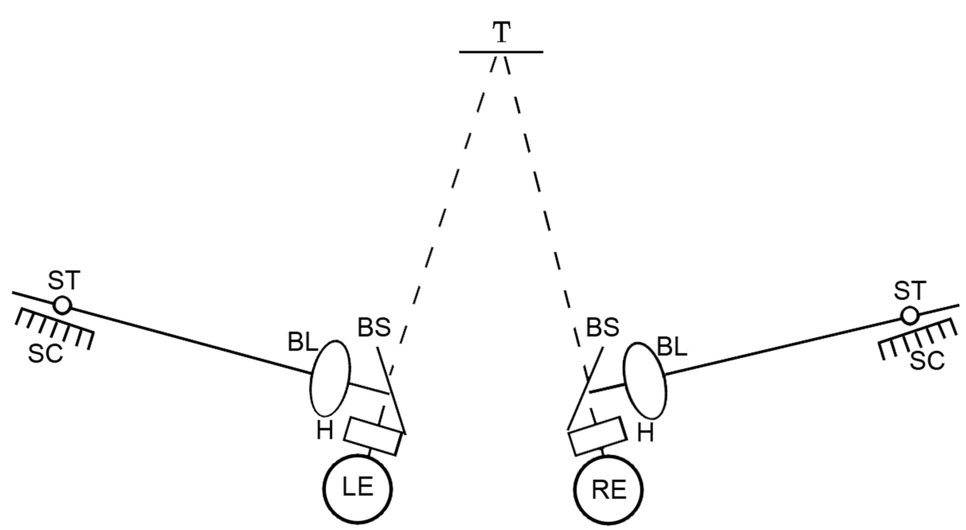

FIGURE 3.
Schematic of Wheastone-Mirror Haploscope. LE = left eye, RE = right eye, H = lens holder, BS = beam splitter, BL = Badal lens, ST = stigma; point source of light, SC = scale reading, T = target. The left stigma visible to the left eye was imaged on a target (T) viewed by that eye through a beam splitter. The subject adjusted the focus of the stigma by moving it toward or away from the 10 D Badal lens while fixating at target T. The stigma is focused when it is optically conjugate with the retina, and the scale reading is converted to accommodation in diopters.

Accommodative response measurements were plotted as a function of accommodative stimuli. Data of a representative subject are shown by the solid curve in Fig. 5. A third-order polynomial function was fitted to the data. The first derivative of the fitting function was calculated to determine two parameters: (1) the nearpoint of accommodation (NPA) describing the maximal accommodation, and (2) the extent of the linear portion of the ASR curve.[9] The NPA was estimated from the zero derivative point at the peak of the ASR function. The ASR data range, which produced slope values >0.40, was considered linear. A linear regression was then fitted to estimate the slope of the linear portion of ASR function, describing the gain of accommodative response. The y intercept

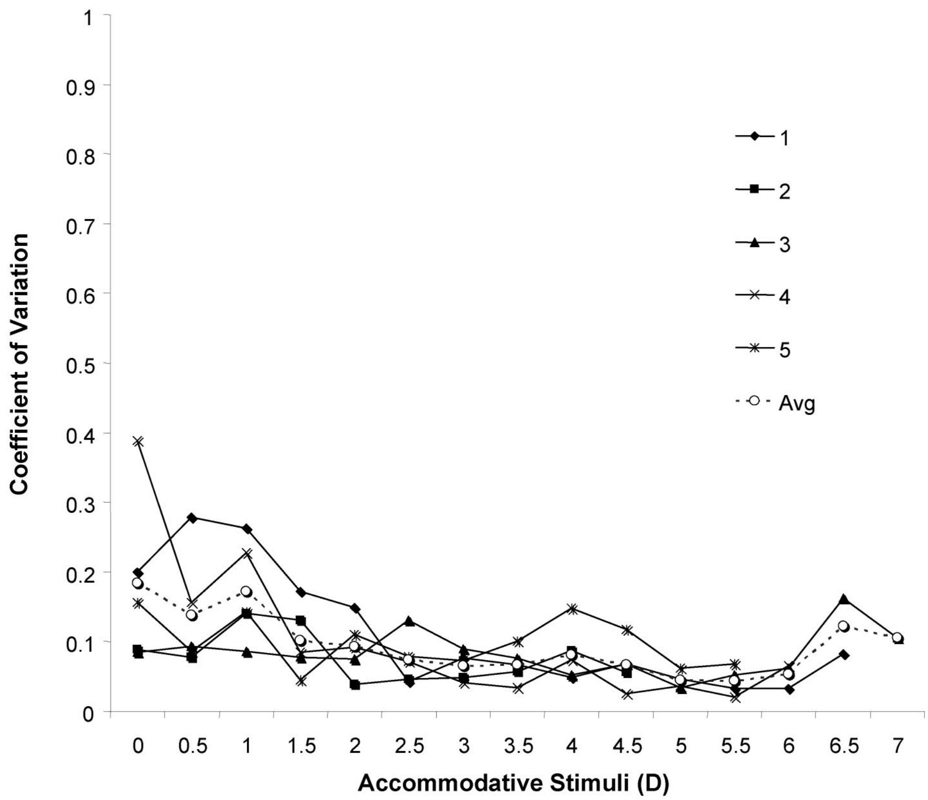

FIGURE 4.

Coefficient of variation is depicted for the different accommodative stimuli over the measured accommodative range in five subjects. The dashed line indicates average COV. The COV is ~0.1 or less for accommodative stimuli >1.5 D.

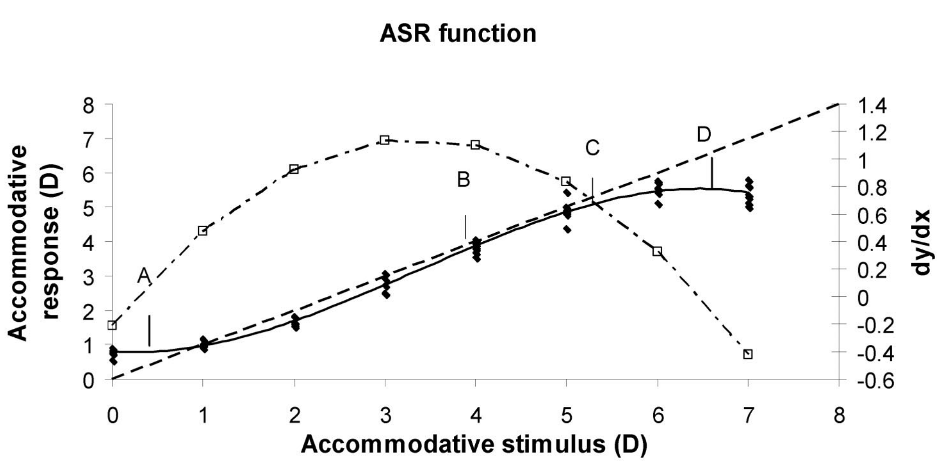

FIGURE 5.

Accommodation response is plotted as a function of accommodative stimulus for a representative subject. The ASR function is illustrated by the black solid curve. The first derivative (open squares, dashed + dotted line) of a third-order polynomial fit (black solid line) to the raw data is shown. The dashed line indicates the 1:1 line where the accommodation responses equal the stimuli. The ASR curve labels describe different response characteristics,[36] where A indicates initial nonlinear region; B, linear region; C, soft saturation zone; D, NPA (or hard saturation region).

(far point of accommodation, FPA) of the function describes the residual accommodative response/bias at 0 D. Two measures of AA were estimated from the data, the first being defined as the nearpoint accommodative response minus the ideal response at optical infinity (NPA-0 D) and the second being defined as the nearpoint accommodative response minus the empirical farpoint accommodative response (NPA-FPA). Spectacle lens effectivity was taken into account while computing the amplitudes.

The open-loop accommodative-convergence response was plotted as a function of closed-loop accommodation response and was fitted by a linear regression function within its linear range. Fitting higher order polynomials to the linear portion of the data did not improve the fit. AC/A ratio and residual vergence response/bias at infinity (far phoria) were estimated from the slope and y intercept of the linear regression, respectively. Similarly, the open-loop accommodation response was plotted as a function of closed-loop vergence response and was fitted by a linear regression function within its linear range. CA/C ratio and residual accommodation response bias at infinity were estimated from the slope and y intercept, respectively.

Statistical Methods

Our primary purpose was to determine whether accommodative responses changed postwear and if so whether they recovered after discontinuation of wear and whether such responses differed between Caucasian and Chinese subjects. Statistical analyses were performed using PASW Statistics 17.0, SPSS software package (SPSS, Chicago, IL). In all analyses, the alpha level for comparison was set at 0.05. A mixed-design analysis of variance was used where the within-subjects factor had three levels (baseline, after 2 months of wear, after 2 months of recovery) and the between-subjects factor was ethnicity with two levels (Chinese vs. Caucasians) for each outcome variable. Model assumptions were checked before fitting the model to the data. A significant interaction effect suggests that the changes in the outcome variable with study visits differed between the two ethnic groups. The within-between interaction effect is of main interest here. For an assumed $\alpha = 0.05$, power 0.8, and interaction effect size (d) = 0.25, a total sample size of 28 subjects were required to detect changes in AA across study visits and ethnicity.[24] Pretreatment (baseline data) were compared between groups using t-tests. Bonferroni correction was applied when necessary to control for family-wise error rate associated with multiple comparisons (alpha 0.05/number of comparisons). Pearson product-moment correlation coefficients were estimated to explore the correlation between variables.

RESULTS

ASR Function

The mean ages of subjects who completed the study were 40.2 (±2.3, 1 SD) and 39.4 (±2.3, 1 SD) years in the Chinese and the Caucasian subjects, respectively. The near-addition lenses were worn on an average for 4.4 ± 1.3 h and 3.7 ± 0.93 h in the Caucasian and Chinese groups, respectively. The wearing times were generally consistent throughout the 2-month treatment period in subjects who completed the study, and the wearing times were not significantly different between the groups ($p = 0.2$). ASR slopes were estimated by linear fit to the linear portion of the ASR function. The R^2 values improved by fitting higher (second and third) order polynomials to the same data; however, the differences were within 0.05, indicating that the linearity assumption is acceptable in this case. Fig. 6A illustrates the slopes of the ASR function at baseline, posttreatment, and recovery in both groups. There was no difference between the ASR slopes across study visits ($p = 0.66$). There was no significant interaction effect between study visit and ethnicity ($p = 0.32$). Also, there were no significant differences in baseline slopes of the ASR function ($p = 0.54$) between Caucasian and Chinese groups.

Fig. 6B shows the intercepts of the ASR function at baseline, posttreatment, and recovery. There was a significant interaction between the study visits and ethnicity ($p = 0.03$), with Caucasian subjects showing greater changes in the ASR intercepts posttreatment when compared with the Chinese group. The baseline ASR intercepts were higher or more myopic in the Caucasian group when compared with the Chinese group ($p = 0.026$). Fig. 6B shows that the ASR intercept for Caucasian subjects dropped approximately 0.35 D (45.3% change from baseline) on average after 2 months of wear and continued to decrease slightly to 0.51 D on average (66.8% change compared with baseline) after 2 months of recovery. The drop in ASR intercept and the lack of recovery in Caucasians was significant ($p = 0.002$) after adjusting for multiple pairwise comparisons. In the Chinese group, there was no such significant change in ASR intercepts across the study visits ($p = 0.8$), possibly because of the low baseline ASR intercepts to begin with when compared with the Caucasians subjects and therefore less room for adaptation.

Accommodative Amplitude

NPA-0 D

AA, defined as the nearpoint accommodative response minus the 0 D ideal response at optical infinity, differed significantly across study visits ($p = 0.022$, $d = 0.32$). There was no significant interaction effect, suggesting that the magnitude of changes in AA did not differ between the groups ($p = 0.49$). For the entire sample, the mean AA was 4.1 D at baseline, reduced significantly by

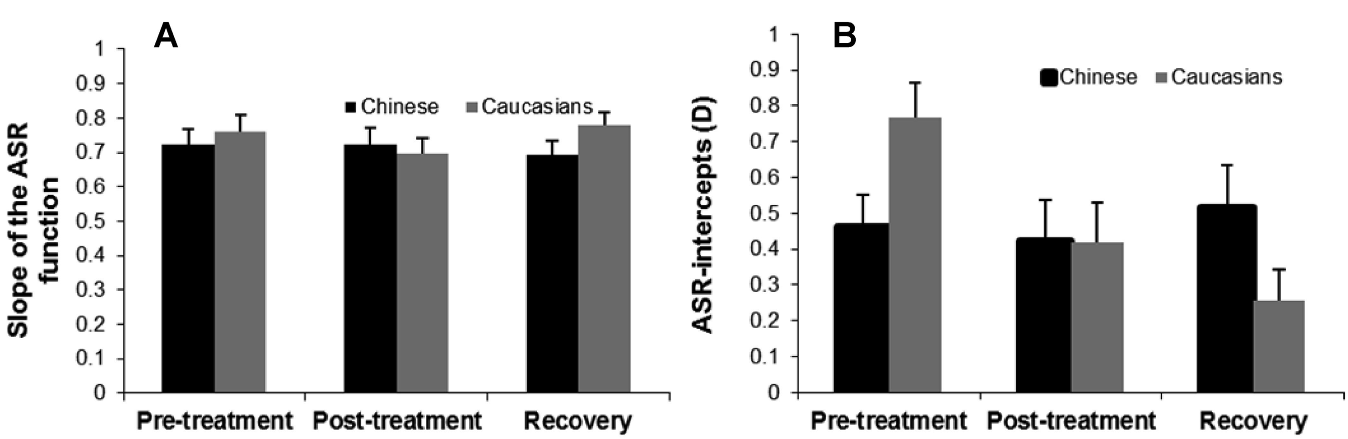

FIGURE 6.
(A) The slope of the ASR function (mean ± 1 SEM) is plotted for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit. (B) Mean (±1 SEM) ASR intercepts are plotted for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit.

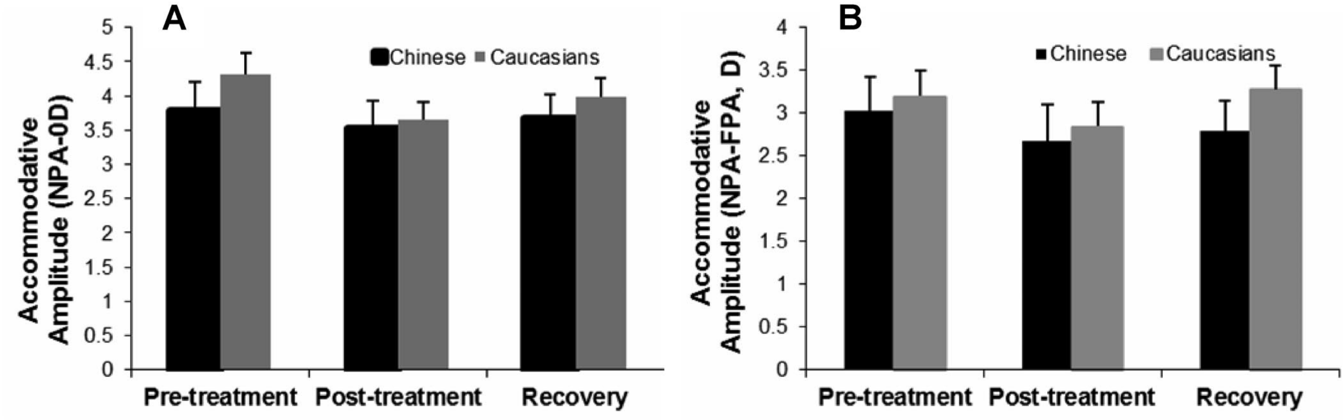

FIGURE 7.

(A) Average accommodative amplitude (NPA-0 D) by study visit are shown for Chinese (black solid bar) and Caucasian (gray bar) subject groups. Error bars represent ±1 SEM. (B) Accommodative amplitude (NPA-FPA D) by study visits are shown for Chinese (black solid bar) and Caucasian (gray bar) subject groups. Error bars represent ±1 SEM.

12.68% to 3.58 D after 2 months of wear ($p = 0.036$), and recovered to 3.83 D after 2 months of discontinuing the reading glasses, with no significant difference from the baseline values ($p = 0.64$). Fig. 7A illustrates the mean AA across study visits for both groups. There was no significant correlation between the changes in AA from pre- to posttreatment (percentage change was computed to account for any differences in baseline AA between subjects) and refractive error or age for both ethnic groups ($p = 0.1$ to 0.66).

Post hoc analysis showed that the pretreatment AA did not differ between the two groups ($p = 0.31$), suggesting that the amplitudes are similar between the two ethnic groups. In the present sample, there were 73.7 and 59% myopic subjects in the Chinese and Caucasian groups, respectively (Fig. 2). Interestingly, there was no correlation between AA and refractive errors in both ethnic groups after partialling out age effect ($p = 0.8$). However, there was a significant and negative correlation between AA and age in Chinese ($r = -0.82$, $p < 0.0001$) and the Caucasian ($r = -0.59$, $p = 0.004$) subject groups after controlling for refractive error. Linear regression demonstrated significant negative relationship between AA and age in Chinese ($-0.65x + 29.94$, $p < 0.0001$) as well as the Caucasian ($-0.37x + 18.85$, $p = 0.004$) subject groups. Chinese subjects demonstrated significantly steeper slopes than the Caucasian subjects (one-tailed, $p < 0.05$).

NPA-FPA

AA defined as the NPA minus the FPA did not differ across study visits ($p = 0.09$). There was no significant interaction effect suggesting that wearing reading glasses for a period of 2 months did not have any significant impact on the AA irrespective of the subject groups ($p = 0.4$). The mean AA at baseline, posttreatment, and recovery are shown in Fig. 7B for the Chinese and Caucasian subject groups.

There was no significant difference between the pretreatment AAs between the Chinese and Caucasian subject groups ($p = 0.7$). We found no correlation between the baseline AA and refractive error after partialling out the age variable in both groups ($p = 0.7$ to 0.9). However, there was a significant negative correlation between the baseline AA and age in the Chinese ($r = -0.79$, $p < 0.0001$) and the Caucasian ($r = -0.48$, $p < 0.023$) groups after controlling for refractive error.

Accommodative Convergence/Accommodation

Fig. 8A plots the mean AC/A ratios at baseline, posttreatment, and recovery. The AC/A ratios (slopes) did not change significantly with treatment ($p = 0.74$) irrespective of the subject groups as shown by an insignificant interaction effect ($p = 0.13$). A similar pattern was observed for AC/A intercepts (Fig. 8B). Statistical models revealed no significant differences in AC/A intercepts from baseline to postwear or postrecovery ($p = 0.42$), and no interaction effects with ethnicity were observed ($p = 0.86$). The mean AC/A intercepts, corresponding to the distance phoria, were 0.19 MA at baseline, 0.25 MA after 2 months of wear, and 0.41 MA after 2 months of recovery.

Convergence Accommodation/Convergence

Fig. 9A plots the mean CA/C ratios at baseline, posttreatment, and recovery. The CA/C ratios were invariant across study visits ($p = 0.63$), and this pattern was similar for both ethnicities ($p = 0.43$). There was no difference between the baseline CA/C ratios between the two groups ($p = 0.3$). Unlike the CA/C ratios, the CA/C intercept (Fig. 9B) that reflects accommodation bias[25] reduced after treatment with the reading glasses ($p = 0.04$). Huynh-Feldt correction was applied to compensate for sphericity violation. The magnitude of changes did not differ between the groups ($p = 0.46$). The mean bias at baseline for the two groups combined were 1.0 D, which significantly reduced to 0.56 D ($p < 0.017$ or 0.05/3) and recovered to 0.7 D after discontinuing the glasses. The results of all the outcome measures are summarized in Table 2.

DISCUSSION

Hitherto, only indirect comparisons of accommodative changes with age exist between Chinese and Caucasian ethnicities. In this report, we present a systematic comparison of adaptive effects of

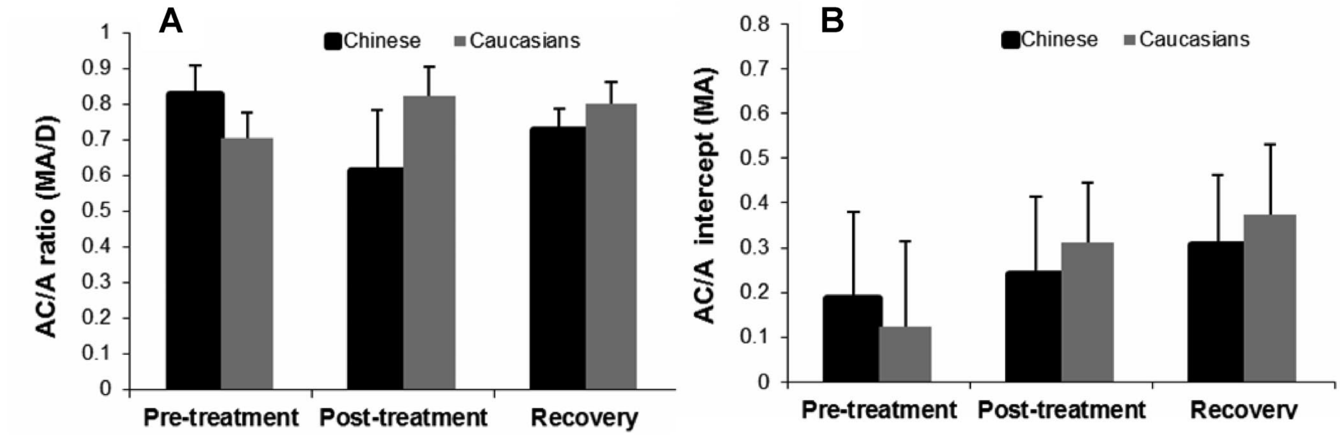

FIGURE 8.

(A) AC/A ratios (mean ± 1 SEM) are plotted for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit. (B) Mean (±1 SEM) vergence bias (as indicated by y intercept of the accommodation vs. convergence plot) is shown for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit.

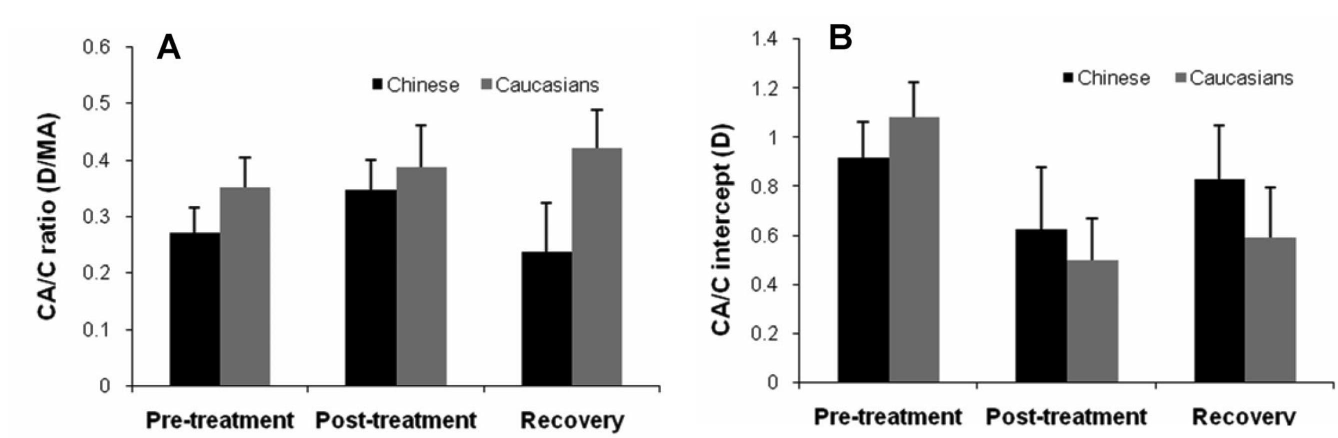

FIGURE 9.

(A) CA/C ratios (mean ± 1 SEM) are plotted for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit. (B) Mean (±1 SEM) convergence-accommodation bias (as indicated by y intercept of the CA/C plot) is shown for Chinese (black solid bar) and Caucasian (gray bar) subject groups by study visit.

first reading spectacles on the accommodative response and its interactions with convergence in these ethnic groups.

Ocular Accommodation in Chinese and Caucasian Subjects

Some studies have suggested an earlier onset of presbyopia in Asian subjects than in Caucasians.[2,26] In contrast, our data showed no statistical difference in the mean baseline AA of the two groups, suggesting similar onsets. Normally, AA declines linearly with age,[2,27] and if the amplitudes are equal between the two ethnic groups, one would not expect any vertical shifts between the two regression lines along the y axis in the accommodation vs. age plots. As expected, we found a significant decline in amplitudes with increasing age in both groups; however, Chinese subjects demonstrated steeper slopes than the Caucasians. The age-related decline in AA was rapid in the Chinese subjects when compared with Caucasian subjects. The apparent lack of significant difference be-

TABLE 2.
Summary of omnibus analysis of variance for each outcome measure

Outcome measure	Study visit (SV)	Ethnicity effect (EE)	Interaction effect (SV × EE)
ASR slope	NS	NS	NS
ASR intercept	NS	NS	S
AA, NPA-0 D	S	NS	NS
AA, NPA-FPA	NS	NS	NS
AC/A ratio	NS	NS	NS
AC/A intercept	NS	NS	NS
CA/C ratio	NS	NS	NS
CA/C intercept	S	NS	NS

The main effects of study visits (SV), ethnicity (E), and interactions between SV and E are depicted.

NS, not significant; S, statistically significant result.

tween the mean AA could be explained by at least two factors: (a) differences in the refractive error distribution between the two groups and (b) a genetically heterogeneous sample. McBrien and Millodot[28] found that the amplitude of accommodation is greater in corrected early- or late-onset myopes followed by emmetropes and hyperopes in an age-matched sample. In the present sample, there were 73.7 and 59% myopic subjects in the Chinese and Caucasian groups, respectively. This suggests that the Chinese subjects may have higher (average) AA simply due to more myopes in the sample, which would help close the gap in AA between the two groups. However, there was no correlation between the refractive error and ocular accommodation in either ethnic group, which is counterintuitive to this reasoning.

It is interesting to note that variations exist in the absolute AA even within Caucasians.[3,26] For example, the average AA in our Caucasian subjects was ~4.32 D (NPA-0 D), which is on the minimum side of expected amplitudes based on large sample data from Caucasians located in mid-Europe.[29] This was true despite accounting for the ~0.6 D overestimation of amplitude measured with the push-up technique reported in that study compared with the Badal optometer[30] used in this work. Nevertheless, our study was able to capture the different rates of presbyopia progression in the two ethnic groups. This result must be further substantiated with a longitudinal study with a large stratified sample.

There are some potential limitations of this study. The causal factors for early presbyopia onset are multifaceted. Associations exist between geographical latitude, ambient temperature, pupil size, rural residence, female sex, alcohol consumption, and presbyopia.[5,31–33] This study was not designed to identify the cause of presbyopia in Chinese and Caucasian subjects. Therefore, our results should be interpreted with caution in light of the above-mentioned factors. Also, we monitored the level of reading glass compliance subjectively; and we hope subjects were not overreporting the glass usage times. Another limitation includes ~25% attrition rate in the study. Attrition bias can affect the validity of the results in longitudinal studies or studies where repeated measurements at multiple time points are required.[34] In our sample, however, equal number of subjects (n = 7, see Fig. 1) from each ethnic group (variable of interest) dropped out, so we ignored the missing data from analysis.

Adaptation to Reading Glasses

Recently, we reported the effect of first reading spectacles on the ASR function and AC/A and CA/C ratios in two distinct age groups.[9] We found age-invariant hyperopic shifts of the near and far points of accommodation after wearing 1.5 D reading spectacles for 2 months, and these shifts were attributed to the relaxation of tonic accommodative bias. Full recovery to baseline did not occur after discontinuing the readers. We found no significant adaptation of the ASR slope and AC/A or CA/C ratios. The lack of change in the cross-link interactions might be due, in part, to limited wearing time as the subjects only wore the readers for ~3.5 h per day for near work. The present results largely confirmed our previous report and extended our findings to two ethnicities, except that the current results showed greater recovery of the nearpoint of accommodation (although not complete) after discontinuing the use of glasses for 2 months.

Targets in the midsagittal plane produce equal amounts of defocus (diopters) and disparity (meter angles) stimuli for any viewing distance.[20] The 1.5 D readers introduced a stimulus conflict between accommodation and convergence by decreasing the effort needed to accommodate for the reading distance. This stimulus conflict can be resolved either by independently adjusting the cross-link interactions or the bias or a combination of both. The empirically measured AC/A and CA/C ratios showed invariance with study visits, indicating that the cross-link interactions are less adaptable in response to short-term use of 1.5 D readers. Instead, our results showed that the accommodative bias adapted and decreased after wearing the reading glasses. It is interesting to note that the baseline CA bias is greater than the ASR bias, perhaps because ASR bias was measured monocularly with convergence at the resting phoria while the CA bias was measured with convergence closed loop. If the eyes were exophoric for the 0 D prism condition, then some fusional convergence would be stimulated, with an associated increase in CA bias. In summary, we found no difference between Caucasian and Chinese groups in terms of adaptation of AA and cross-link interactions after wearing the glasses for 2 months.

Jiang and Ramamirtham[11] and Miles et al.[35] have shown significant changes in cross-link gains after 30 min of viewing through gadgets that produce stimulus conflicts between the accommodation and vergence systems. We did not observe such changes. There are at least two reasons for the lack of gain changes in the present study: (a) AC/A and CA/C ratios were not measured immediately after discontinuing the reading glasses. Our subjects experienced normal binocular viewing/exposure for a couple of hours before coming to the laboratory for posttests, and (b) subjects did not undergo active training while wearing the reading glasses for near work. On the contrary, for example, Miles et al. did not permit normal binocular viewing after adaptation to optical gadgets and likely measured transient gain changes. They also instructed their subjects to actively shift fixation to view objects at different distances (30 cm to 1000 m) while viewing through the optical gadgets.

CONCLUSIONS

The present results showed no significant ethnic differences in the baseline average AA or cross-link interactions. Our sample showed that the rate of presbyopia progression with age might be faster in Chinese than the Caucasian subjects. This result would be confirmed on a large stratified sample. The residual AA adapts to decrease in response to first time short-term wear of reading glasses during the incipient stages of presbyopia, but the differences based on ethnicity are not significant. The daily use of reading spectacles had no impact on the accommodation and convergence cross-link interactions in both ethnicities.

ACKNOWLEDGMENTS

This work was supported by Essilor Grant, NIH grant EY017678, and UCB-CRC unrestricted fund.

The first two authors contributed equally to this work.

Received October 17, 2011; accepted December 12, 2012.

REFERENCES

1. Kragha IK. Measurement of amplitude of accommodation. Ophthalmic Physiol Opt 1989;9:342–3.
2. Edwards MH, Law LF, Lee CM, Leung KM, Lui WO. Clinical norms for amplitude of accommodation in Chinese. Ophthalmic Physiol Opt 1993;13:199–204.
3. Duane A. An attempt to determine the normal range of accommodation at various ages, being a revision of Donder's experiments. Trans Am Ophthalmol Soc 1908;11:634–41.
4. Ong J. Southeastern Asian refugees' presbyopia. Percept Mot Skills 1981;53:667–70.
5. Miranda MN. The geographic factor in the onset of presbyopia. Trans Am Ophthalmol Soc 1979;77:603–21.
6. Weale R. Chinese and European amplitudes of accommodation. Ophthalmic Physiol Opt 1993;13:431.
7. Rosenfield M, Carrel MF. Effect of near-vision addition lenses on the accuracy of the accommodative response. Optometry 2001;72: 19–24.
8. Shapiro JA, Kelly JE, Howland HC. Accommodative state of young adults using reading spectacles. Vision Res 2005;45:233–45.
9. Vedamurthy I, Harrison WW, Liu Y, Cox I, Schor CM. The influence of first near-spectacle reading correction on accommodation and its interaction with convergence. Invest Ophthalmol Vis Sci 2009;50: 4215–22.
10. McGarry MB, Manning TM. The effects of wearing corrective lenses for presbyopia on distance vision. Ophthalmic Physiol Opt 2003;23: 13–20.
11. Jiang BC, Ramamirtham R. The adaptive effect of narrowing the interocular separation on the AC/A ratio. Vision Res 2005;45: 2704–9.
12. Judge SJ, Miles FA. Changes in the coupling between accommodation and vergence eye movements induced in human subjects by altering the effective interocular separation. Perception 1985;14: 617–29.
13. Fry GA. The effect of age on the ACA ratio. Am J Optom Arch Am Acad Optom 1959;36:299–303.
14. Fincham EF, Walton J. The reciprocal actions of accommodation and convergence. J Physiol 1957;137:488–508.
15. Bhopal R. Glossary of terms relating to ethnicity and race: for reflection and debate. J Epidemiol Community Health 2004;58:441–5.
16. Badal M. Optometre metrique international: pour la measure simultance de la refraction et de l'acuite visuelle meme chez les le illettres. Annales D'Oculistique (Paris) 1876;75:101–17.
17. Hennessy RT. Behavior Research Methods & Instrumentation. Austin, TX: Psychonomic Journals, Inc.; 1972.
18. Ogle KN. Optics: An Introduction for Ophthalmologists, 2nd ed. Springfield, IL: Thomas; 1968.
19. Wang L, Shirayama M, Koch DD. Repeatability of corneal power and wavefront aberration measurements with a dual-Scheimpflug Placido corneal topographer. J Cataract Refract Surg 2010;36: 425–30.
20. Nguyen D, Vedamurthy I, Schor C. Cross-coupling between accommodation and convergence is optimized for a broad range of directions and distances of gaze. Vision Res 2008;48:893–903.
21. Ogle KN. Researches in Binocular Vision. Philadelphia, PA: Saunders; 1950.
22. Tsuetaki TK, Schor CM. Clinical method for measuring adaptation of tonic accommodation and vergence accommodation. Am J Optom Physiol Opt 1987;64:437–49.
23. Schor C, Wesson M, Robertson KM. Combined effects of spatial frequency and retinal eccentricity upon fixation disparity. Am J Optom Physiol Opt 1986;63:619–26.
24. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175–91.
25. Jiang BC, Woessner WM. Dark focus and dark vergence: an experimental verification of the configuration of the dual-interactive feedback model. Ophthalmic Physiol Opt 1996;16:342–7.
26. Raphael J. Accommodational variations in Israel, 1949–1960. Br J Physiol Opt 1961;18:181–5.
27. Donders FC. On the Accommodation and Refraction of the Eye (English translation by W.D. Moore). London: The New Sydenham Society; 1864.
28. McBrien NA, Millodot M. Amplitude of accommodation and refractive error. Invest Ophthalmol Vis Sci 1986;27:1187–90.
29. Hofstetter HW. A comparison of Duane's and Donder's tables of the amplitude of accommodation. Am J Optom Arch Am Acad Optom 1944;21:345–63.
30. Somers WW, Ford CA. Effect of relative distance magnification on the monocular amplitude of accommodation. Am J Optom Physiol Opt 1983;60:920–4.
31. Nirmalan PK, Krishnaiah S, Shamanna BR, Rao GN, Thomas R. A population-based assessment of presbyopia in the state of Andhra Pradesh, south India: the Andhra Pradesh Eye Disease Study. Invest Ophthalmol Vis Sci 2006;47:2324–8.
32. Weale RA. Human ocular aging and ambient temperature. Br J Ophthalmol 1981;65:869–70.
33. Weale RA. Epidemiology of refractive errors and presbyopia. Surv Ophthalmol 2003;48:515–43.
34. Ahern K, Le Brocque R. Methodological issues in the effects of attrition: simple solutions for social scientists. Field Methods 2005; 17:53–69.
35. Miles FA, Judge SJ, Optican LM. Optically induced changes in the couplings between vergence and accommodation. J Neurosci 1987; 7:2576–89.
36. Ciuffreda KJ, Hokoda SC, Hung GK, Semmlow JL. Accommodative stimulus/response function in human amblyopia. Doc Ophthalmol 1984;56:303–26.

Indu Vedamurthy
University of Rochester
Meliora Hall, Box 270268
Rochester, New York 14627-0268
e-mail: ivedamurthy@bcs.rochester.edu